

COMPUTERIZATION OF TACTICAL AIRCRAFT
PERFORMANCE DATA FOR FLEET APPLICATION

William Morris Siegel

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

COMPUTERIZATION OF TACTICAL AIRCRAFT
PERFORMANCE DATA FOR FLEET APPLICATION

by

William Morris Siegel

June 1978

Thesis Advisor:

L.V. Schmidt

Approved for public release; distribution unlimited.

T184584

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Computerization of Tactical Aircraft Performance Data for Fleet Application		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; June 1978
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William Morris Siegel		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE June 1978
		13. NUMBER OF PAGES 52
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) NATOPS Naval Air Training and Operating Procedures Standardization Tactical Aircraft Performance Data Computerized Aircraft Performance Data		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The nature of operations, variety of missions and configurations, and requirement for rapid response of fleet tactical aircraft has given rise to a unique problem within the Naval Aviation community, this being the interface between the aircrews and the aircraft performance prediction information supplied via charts and data in the Naval Air Training and Operating Procedures Standardization (NATOPS)		

(20. ABSTRACT Continued)

Manuals. The data presented are not optimally used due to the method of presentation and the time and effort required to extract useful predictions. This investigation addressed the problem by developing a suitable method of NATOPS curve presentation that has sufficient simplicity and accuracy for application to current compact computers. The procedure is defined and numerical algorithms produced which demonstrate the feasibility and desirability of this type of implementation.

Approved for public release; distribution unlimited.

Computerization of Tactical Aircraft
Performance Data for Fleet Application

by

William Morris Siegel
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1965

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

June 1978

Theris
S 4934
C. 1

ABSTRACT

The nature of operations, variety of missions and configurations, and requirement for rapid response of fleet tactical aircraft has given rise to a unique problem within the Naval Aviation community, this being the interface between the aircrews and the aircraft performance prediction information supplied via charts and data in the Naval Air Training and Operating Procedures Standardization (NATOPS) Manuals. The data presented are not optimally used due to the method of presentation and the time and effort required to extract useful predictions. This investigation addressed the problem by developing a suitable method of NATOPS curve presentation that has sufficient simplicity and accuracy for application to current compact computers. The procedure is defined and numerical algorithms produced which demonstrate the feasibility and desirability of this type of implementation.

TABLE OF CONTENTS

I.	INTRODUCTION -----	8
II.	DISCUSSION -----	12
	A. GUIDELINES -----	12
	B. COMPUTATIONAL METHOD USED -----	14
	C. EXAMPLE OF COMPUTATIONAL METHOD -----	25
III.	RESULTS -----	30
IV.	CONCLUSIONS AND RECOMMENDATIONS -----	33
	APPENDIX A: A7E NATOPS TAKE-OFF SECTION -----	34
	APPENDIX B: A7 NATOPS PROBLEM -----	38
	APPENDIX C: LEAST SQUARES FIT APPROXIMATION -----	40
	APPENDIX D: COMPUTER PROGRAM -----	47
	LIST OF REFERENCES -----	51
	INITIAL DISTRIBUTION LIST -----	52

LIST OF FIGURES

1.	Altitude versus polynomial coefficients for a series of third degree equations -----	22
2.	A_{m1} versus Altitude -----	27
3.	A_{m2} versus Altitude -----	27
4.	A_{m3} versus Altitude -----	28
5.	A_{m4} versus Altitude -----	28

ACKNOWLEDGMENT

My thanks to Captain Clyde H. Tuomela, USN (Ret),
for his inspiration and support. My thanks also to
Professors R.E. Ball, D.K. Layton, and my thesis advisor
L.V. Schmidt for their professional and academic assistance.

I. INTRODUCTION

This investigation was commenced in response to a generally agreed upon, but not officially defined, fleet problem, i.e., the interface between operational aircrews and their aircraft performance prediction data. Currently, in the rear sections of all fleet aircraft Naval Air Training Operations and Standardization (NATOPS) Manuals [Ref. 5], an extensive set of performance prediction charts are included for aircrew use. An example of these charts for the A-7E aircraft is included as Appendix A. These charts represent performance predictions based upon interpolations and extrapolations of flight test data compiled at the Naval Air Test Center, Patuxent River, Maryland. They are included in the manuals for use by aircrews in the prediction of aircraft performance items such as take-off roll and velocities, cruise, emergency divert (Bingo), etc. The take-off prediction parameters starting on page 11-36 of Appendix A will be used as a representative example and have been prepared on fold-out sheets for ease of reference. To predict take-off parameters, the aircrew member must enter the chart on page 11-36 of the NATOPS Manual with runway temperature and pressure altitude. He must interpolate as necessary between the given lines and proceed as in the dotted line example (refer to the fold-out of Appendix A numbered 11-36) to the chart for the appropriate double datum selection (an

engine parameter) to arrive at the corresponding take-off factor. With this number he must then proceed to page 11-37 and, after interpolating for gross weight correction, proceed as indicated to arrive at the basic ground roll distance. Proceeding to page 11-38, he next must apply a correction for relative humidity, utilizing the relationship in the appropriate paragraph, followed by tracing through subsequent graphs to correct for relative wind (which is computed from given tower winds and runway heading), runway slope, center of gravity position, and trailing edge flap position. Similar graphical procedures exist for all other aircraft performance predictions. A compact equivalence of these charts, known as "Pocket Check Lists", are carried by all aircrews in flight for ready reference. In actual practice individual squadrons have generated numerous NATOPS data cards which represent normally encountered conditions and were derived from the NATOPS charts. In the take-off data prediction example ten input parameters were required to compute take-off roll and velocity. Using the charts has proven to be cumbersome, time consuming, and prone to error. The use of pocket check lists is more convenient but less accurate, and the individual squadron knee-board cards cover only a few nominal situations. The computation of take-off roll is relatively simple when compared with determining the parameters to establish an optimum flight profile for a complex weapons delivery mission. The aforementioned complex

problem involves a similar use of cruise, drag count, climb and descent, etc. charts. As a further illustration of the problem's magnitude, the former Director of the School of Aviation Safety at the Naval Postgraduate School, Monterey, California, has repeatedly required that each member of a one-week Command Safety Course (prospective squadron commanding officers) complete the weapons delivery problem included here as Appendix B. This is considered as a typical fleet contingency planning problem, requiring that in one hour these experienced aviators compute the maximum mission range with the given inputs and aircraft parameters. The results of these tests, given to a class of sixteen such aviators, were described by the Director as [Ref. 3]:

"It is a startling but typical fact that the correct answer of 538 NM was not achieved by any member of the class. The closest answer was in error by 126 miles and the spread of answers ranged from 336 to 868 NM. Additionally the correct answer was attained by the class instructor only after a measured 16 hours of effort with the NATOPS Manual."

The preceding example serves as a graphic illustration of a widely accepted problem, the elements of which may be summarized as:

1. The only complete and accurate performance prediction data available to fleet aircrews are those provided by the performance chart sections of the appropriate aircraft NATOPS Manuals.

2. Experienced fleet aviators do not use the source information for daily computation of NATOPS problems with enough regularity to insure competency.

3. Personal experience and interviews with fleet aviators indicated that the NATOPS performance presentation contained highly useful and vital data but was too cumbersome, and data extraction too time consuming, for regular operational use.

The purpose of the studies described herein was to examine an alternate approach for assisting the aircrew member to solve the various aircraft performance problems which are required for safe and effective operation of a Naval aircraft in fulfilling its' mission. The subsequent discussion will proceed with the assumptions made, the method used for the solution, and the results of this study.

II. DISCUSSION

A. GUIDELINES

At the onset of the investigation a set of guidelines was adopted to limit its scope and provide a definitive goal. This was deemed necessary because of the controversy within the aviation community over all facets of NATOPS including the validity of some of the data. It was beyond the scope of this investigation to question that validity or investigate any reported discrepancies.¹ The most current NATOPS data available are the official fleet standard and it was merely the representation of those data that inspired this study. Thus, from the above discussion the first guideline was defined:

1. Any method of representation of NATOPS data must be compared to the officially published NATOPS data for accuracy and completeness.

Throughout the life cycle of an aircraft, numerous changes to the NATOPS procedures and performance data are published which represent revisions due to lessons learned through extensive operating and testing. The realization of this fact led to guideline number two:

¹During the course of this investigation several such discrepancies were found and changes submitted in accordance with existing change submittal procedures.

2. To remain useful and current, any system of data presentation must be adaptable to changes as they are promulgated.

The mission variety and uniqueness of carrier based, single-seat aircraft, especially under emission control conditions, make it highly desirable that the information contained in NATOPS be readily available to the pilots while in the aircraft. Airborne workload, lack of additional cockpit space, and lack of time in critical situations led to the third guideline:

3. The data presentation system utilized must be light, small, simple to use, reliable, and require a minimum amount of pilot's attention during use to insure acceptability from the standpoints of mission accomplishment and flight safety.

Finally a standard of measurement was defined for accuracy comparison with NATOPS data. These figures were chosen based upon the experience of the author, and were used to determine when the degree of complexity of the computer solution was adequate for this application. Guideline four lists the desired computational tolerances.

4. One knot of airspeed
100 feet of altitude of ground-roll distance
100 pounds of weight
Ten seconds of time
100 pounds of fuel

After defining the above, an investigation was commenced toward utilizing digital computers as a solution, with the goal being the reduction of the data contained in NATOPS into an algorithm for use in desk , "hand-held", and/or existing on-board aircraft calculators and computers. Informal liaison with senior and junior attack and fighter fleet aviators has indicated strong support for a solution of this type when restrained to the stated guidelines.

B. COMPUTATIONAL METHOD USED

Procedurally the entire project was subdivided as follows:

1. Investigation of a numerical technique for general computer use.
2. Application of ~~the~~^{1.4} numerical technique to specific aircraft performance data
3. Investigation of hardware and implementation of the results of part 2, above, for fleet use.

This investigation was principally concerned with step 1, above, while subsequent and concurrent investigations were proceeding with the work in the other areas. Two basic techniques were investigated:

1. Data Storage
2. Computational technique

Data storage, while mathematically trivial, was determined to be unacceptable for this application due to the amount required to insure completeness. An examination of a set of curves (e.g., take-off) showed a near infinite number of solutions for the ten input variables used. The current squadron method for bypassing NATOPS by using knee-board cards for quick reference to nominal solutions corresponds to the data storage method on a much smaller scale. While many more data points could be stored utilizing calculators, it was felt that a table lock-up solution would lead to incorrect interpolation and extrapolation when seeking information utilizing parameters other than the ones stored. Interpolation routines could be utilized when this occurred, but each routine would vary depending upon the relationship of the data points. In many cases the data vary in a different non-linear manner, thus causing the number of routines used to be unacceptably large in order to produce the desired results. Additionally, the number of storable points is limited by computer size. Fleet tactical aircraft continually operate with widely varying fuel, gross weight and drag coefficient values. These parameters greatly affect nearly all computations made. The data storage method for mission planning purposes would require a near infinite number of precomputed solutions using these parameters, and would therefore be too complex for use. Finally the computer state-of-the-art was sufficiently advanced to and even

beyond the capability for computing the performance of any number of inputs, utilizing a fraction of the memory space required for data storage.

The data storage method, after a brief trial, was not investigated further. A summary of the reasons for this decision would include:

1. The number of variables involved would require too much data storage space to produce the desired result.
2. A reduced set of data would be of little value in mission planning situations due to the accuracy of the required results.
3. Inaccurate (and thus unsafe) interpolation and extrapolation of the stored data would be a natural out-growth of this type of system (similar to the current use of knee-board cards).
4. Computer programming state-of-the-art was far advanced beyond the requirement for this type of method.

The computational method was considered to be well within the capability of "hand-held" calculators from both memory size and computational standpoints. The basic steps for the implementation of this method are listed below:

1. Reduce the individual curves or sets of data to analytical expressions.
2. Coordinate these expressions, of each of the above, to output the dependent variable for each chart or family of curves, providing for interpolation between the curves.
3. Coordinate the inputs and individual curve outputs into a computer program for validation and pilot use.

The method used for reducing the curves and charts to analytical expressions was simply the Least Squares Fit method. A precise explanation of this method can be found in Refs. 1 and 2. Appendix C contains a brief explanation and sample application of the technique. The majority of the curves or data sets found in NATOPS could be sufficiently described by first, second, or third degree polynomials. This fact was assumed from intuition and supported by numerous iterative curve fits. A variety of computer programs were in existence to aid in producing the desired solutions. The Hewlett-Packard (HP) 9830 desk calculator had available one such program and was used for this analysis (c.f., Reference 6 for a detailed description and set of instructions for use of this technique). Prior to commencement of the data reduction, photographically enlarged versions of the charts under investigation were obtained to aid in the

precise recording of information. Using these charts the following procedure was utilized to produce the analytical expressions for each individual curve:

1. Record data points from each curve of a family of curves presented on the chart (Refer to the foldout charts for take-off prediction provided in Appendix A).
2. Utilize these points in the HP polynomial regression program to generate the coefficients of the analytical expression of sufficient degree for the curve being analyzed.
3. Use the coefficients generated to check polynomial accuracy when compared to the NATOPS curves.
4. Iterate the procedure, reducing the degree of the polynomial in an attempt to simplify the expressions and retain sufficient accuracy to comply with the specifications of guideline 4.

Once a set of equations was obtained for a family of curves, an investigation was commenced to determine a simple method of coordinating the curves, and providing a method of producing an output for those input parameters which might fall between the curves of a family. This presented the greatest problem. The curves of the top chart

on page 11-38 of Appendix A were used as an example (fold-out provided). Given the set of five polynomial expressions corresponding to the respective curves for runway pressure altitude, a linear interpolation routine was produced and tested to predict values between the curves. This routine represented the first attempt at providing a means of accurately computing values between the curves. The independent variables were the pressure altitude and the runway temperature. Using the interpolation routine for a pressure altitude of 2,595 feet and 95 °F, for example, the program first calculated the output from the 2,000 foot curve polynomial. It then did the same for the 4,000 foot polynomial and linearly interpolated to find a value for the original input of 2,595 feet. This procedure produced unacceptable results for the reasons stated in the following:

1. The linear interpolation was not a true model of the actual variance between the curves. A visual inspection revealed that the spacing between the curves increased with altitude. An attempt was made to correct the effect by multiplying the result by a complicated bias factor with analytically acceptable results. The method used to arrive at this factor was highly iterative and time consuming and not considered an acceptable procedure considering the number of curves to be analyzed.

2. Additionally the program required for selecting the curves for interpolation for a given input, complete with interpolation routine, was considered too lengthy and repetitive for small calculator use. This would be especially critical if the family of curves contained many individual curves, as do those on page 11-38 of Appendix A.

Given that the method of linear interpolation between curves of a family was unacceptable for the reasons above, an alternate method of expressing a family of curves analytically was investigated. This method was suggested by Lt. Keith Winters [Ref. 4]. It will be explained using the example contained in the following paragraphs.

The problem was to take a set of polynomials of the same degree representing a family of curves and reduce these to an equation or small set of equations that would generate a solution for these polynomials or any value in between the curves they represent.

Given was a set of equations for the five curves of the previous example (all of the same degree) of the form

$$\begin{aligned}
 Y_1 &= A_{11} + A_{12}X + A_{13}X^2 \dots A_{1N}X^{N-1} \\
 Y_2 &= A_{21} + A_{22}X + A_{23}X^2 \dots A_{2N}X^{N-1} \\
 &\vdots \\
 Y_m &= A_{m1} + A_{m2}X + A_{m3}X^2 \dots A_{mN}X^{N-1}
 \end{aligned}$$

or more specifically for this example

$$Y_1 = A_{11} + A_{12}X + A_{13}X^2 + A_{14}X^3 \quad \begin{array}{l} 0 \text{ feet} \\ \text{pressure} \\ \text{altitude} \end{array}$$

$$Y_2 = A_{21} + A_{22}X + A_{23}X^2 + A_{24}X^3 \quad 1000 \text{ feet}$$

$$Y_3 = A_{31} + A_{32}X + A_{33}X^2 + A_{34}X^3 \quad 2000 \text{ feet}$$

$$Y_4 = A_{41} + A_{42}X + A_{43}X^2 + A_{44}X^3 \quad 4000 \text{ feet}$$

$$Y_5 = A_{51} + A_{52}X + A_{53}X^2 + A_{54}X^3 \quad 8000 \text{ feet}$$

The A_{mn} terms were the polynomial coefficients produced by the Least Squares Fit program for each curve of chart 1. The Y_m terms were the fictitious numbers assigned as the output dependent variables of chart 1 (input to chart 2) and X was the independent variable, temperature, of the same example. Again it was desired that, given any altitude and temperature within the chart limits, a Y could be computed precisely. To do this the program must first take the given altitude and generate either computationally, or from memory, the coefficients of the corresponding third degree polynomial. To provide for the computation of these coefficients separate plots were made of the A_{m1} , A_{m2} , A_{m3} and A_{m4} coefficients using their corresponding input altitude values as abscissae. Figure 1 illustrates the concept.

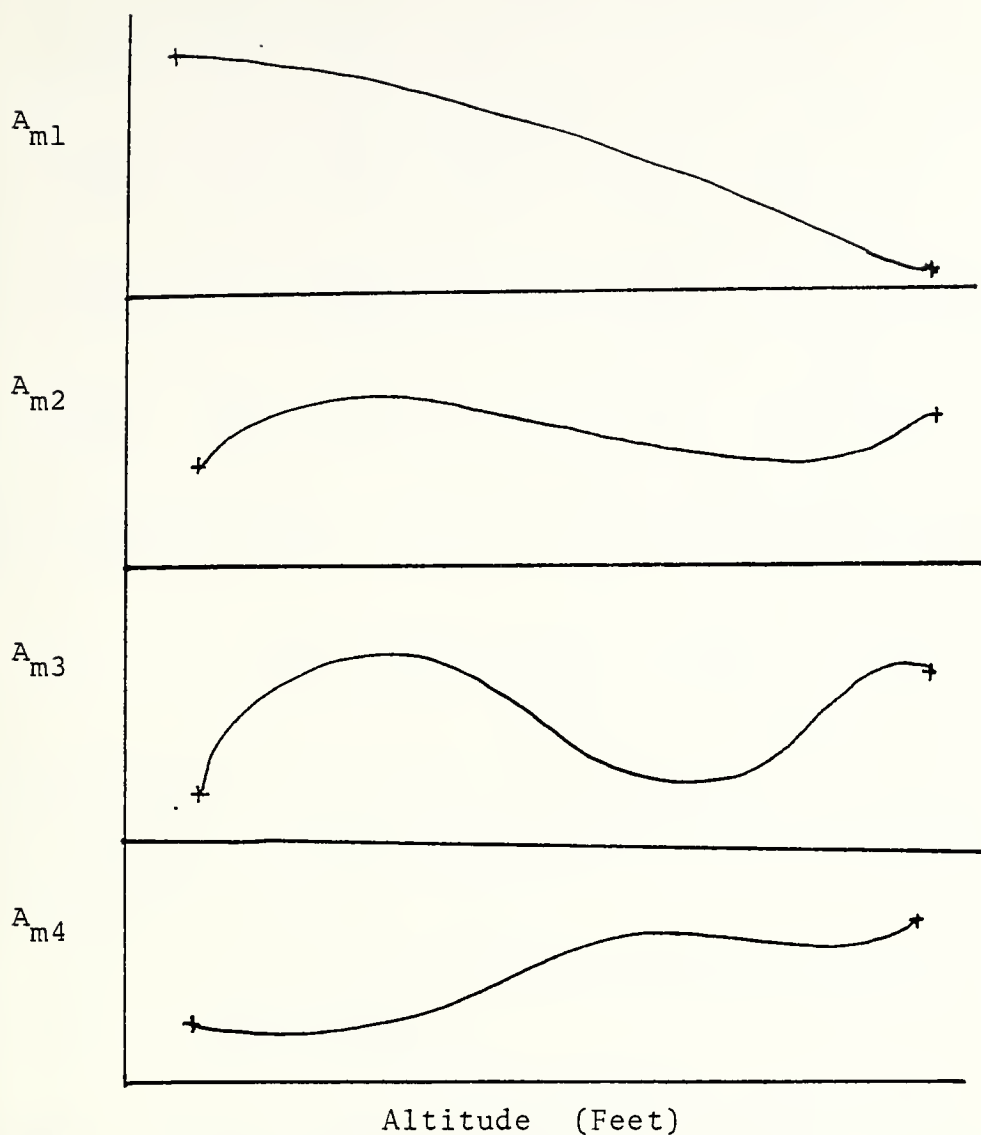


Figure 1. Altitude versus polynomial coefficients for a series of third degree equations

Since each curve contained five data points, a fourth degree (or co-location) polynomial was plotted and the coefficients produced by the HP 9830 program. With these coefficients (Bcd) equations of the form below were produced:

$$A_{m1} = B_{11} + B_{21}M + B_{31}M^2 + B_{41}M^3 + B_{51}M^4$$

$$A_{m2} = B_{21} + B_{22}M + B_{23}M^2 + B_{42}M^3 + B_{52}M^4$$

$$A_{m3} = B_{31} + B_{32}M + B_{33}M^2 + B_{43}M^3 + B_{53}M^4$$

$$A_{m4} = B_{41} + B_{42}M + B_{43}M^2 + B_{44}M^3 + B_{45}M^4$$

These equations when used with the following equation

$$Y = A_{m1} + A_{m2}X + A_{m3}X^2 + A_{m4}X^3$$

would produce the desired output for any value of temperature and altitude. The following chart of symbol definitions was included to ensure clarity:

M = Any value of pressure altitude between 0 and 8000 feet

x = Any value of temperature between 0 and 120°F

Y = The fictitious number representing the output of chart 1 for any given input

Bcd cd.
Bcd = Coefficients of the polynomials used to predict the corresponding coefficient of the Y polynomial for any given input pressure altitude (M)

A_{mn} = The coefficient of the x polynomial used to generate the output number of chart 1 from the given temperature.

The task of the person attempting to program a set of NATOPS curves using this technique is summarized below:

1. Generate the coefficients for each curve by:
 - a. Recording data points from the curves.
 - b. Utilize a computer solution or manually fit the points to output a polynomial of the same degree representing each curve.
2. Plot the similar coefficients of each curve as a dependent variable against the corresponding independent variable as was done in Figure 1.
3. Obtain polynomial expressions of sufficient degree for each of these coefficient curves.
4. Write a computer algorithm that will perform the following:
 - a. Utilize the polynomials of step 3 to generate the coefficients of the polynomials of step 2.
 - b. Utilize the coefficients generated in step 4a. in a polynomial that will output the independent variable of a family of curves.

These steps are a general description of the successful procedure which was generated by this investigation. A detailed example using actual numbers has been included in the next section for reference purposes. Throughout this explanation, emphasis has been placed upon the need for

interpolating accurately for any value within the given curves. The method used also provides for mathematic extrapolation outside the limits of the given NATOPS curves. Care was taken not to provide for this extrapolation in any of the programs generated by this technique. This was done either by limiting the range of the independent variables which the program would accept to values within the stated NATOPS limits, or by ensuring that the output of each separate calculation did not exceed the corresponding chart limits. Mathematical extrapolation of NATOPS data, without flight test verification and approval from the Naval Air Test Center, can lead to a computer prediction that does not correspond to aircraft performance. While precise interpolation is well within the capability of the process developed by this investigation, extrapolation in this case is dangerous and was not within the intent of the study.

C. DETAILED EXAMPLE OF THE COMPUTATIONAL METHOD

The computational steps listed on page 24 were performed for the take-off charts of the A7E NATOPS manual and were included as an example. The number designation of each step corresponds to the instruction as listed. The problem was to generate a set of equations that would describe the family of curves on page 11-36 (Top chart) of Appendix A and provide for interpolation between all curves to output

the dependent variable² to be used in the subsequent chart on that page.

- 1a. The data shown below were extracted from the top chart of page 11-36 Appendix A.

Alt (Feet)	0	2000	4000	6000	8000
Temp°F					
0	13.6	12.6	11.4	10.0	8.3
20	13.3	12.4	11.2	9.8	7.9
40	12.9	11.9	10.5	9.1	7.1
60	11.9	10.8	9.3	7.4	5.2
80	10.6	9.1	7.2	4.8	1.6
100	8.5	6.6	4.2	-	-
120	5.0	-	-	-	-

- 1b. These data were entered into the aforementioned HP 9830 computer program, producing the following coefficients of a thirddegree polynomial of the form

$$Y = A_{m1} + A_{m2}X + A_{m3}X^2 + A_{m4}X^3$$

where

m = altitude

X = temperature

²It may be noted that the chart used does not have printed values for the dependent variable. In NATOPS curves these are not required since the normal procedure is to proceed graphically from chart to chart. For the numerical analysis of this study a set of fictitious numbers was assigned to the dependent variable of this chart and to the independent variable of chart 2 page 11-36.

Coefficients	A_{m1}	A_{m2}	A_{m3}	A_{m4}
0	1.3×10^1	-1.9×10^{-2}	1.9×10^{-4}	-5.2×10^{-6}
2000	1.2×10^1	-1.6×10^{-3}	-2.9×10^{-4}	-2.9×10^{-6}
4000	1.1×10^1	-3.1×10^{-3}	-3.2×10^{-4}	-3.7×10^{-6}
6000	1×10^1	4.5×10^{-3}	5.4×10^{-4}	-4.2×10^{-6}
8000	8.3×10^0	-2.0×10^{-2}	2.8×10^{-4}	-1.4×10^{-5}

2. The coefficients were then plotted against altitude as depicted in Figures 2, 3, 4, and 5.

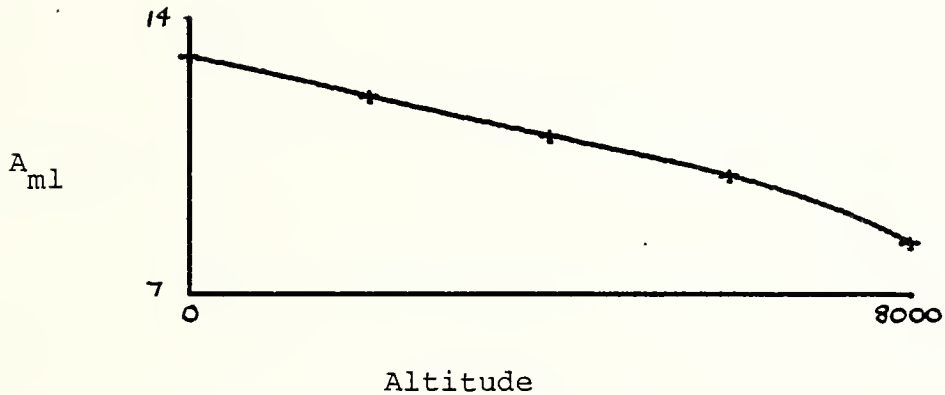


Figure 2: A_{m1} versus Altitude

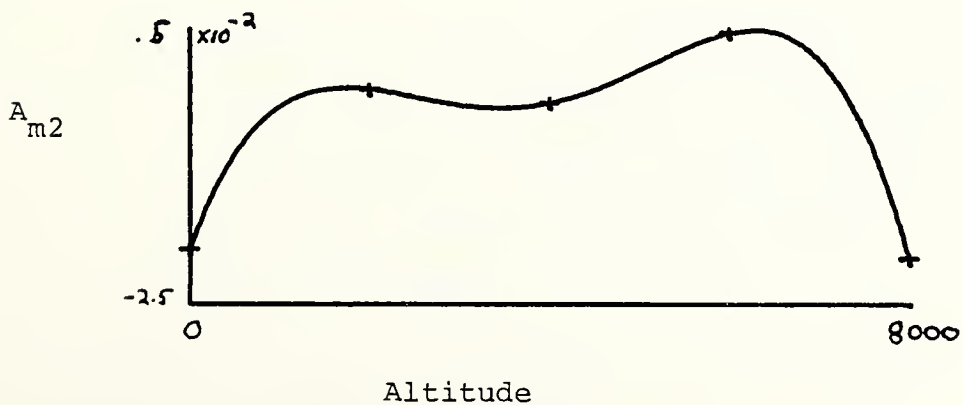


Figure 3: A_{m2} versus Altitude

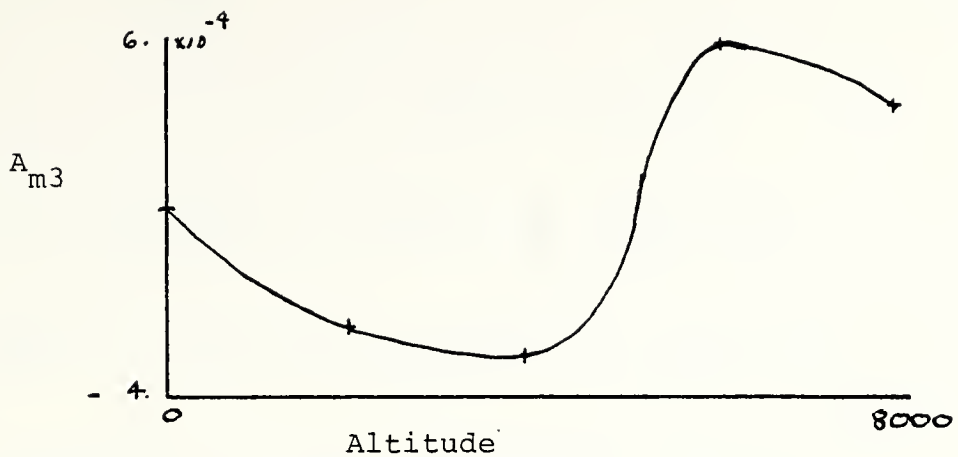


Figure 4: A_{m3} versus Altitude

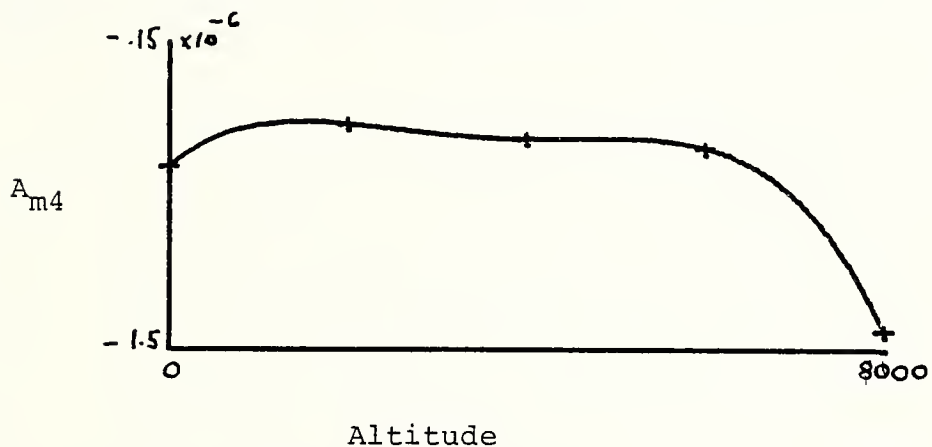


Figure 5: A_{m4} versus Altitude

3. Using the HP 9830 computer program as above the coefficients of each of these third degree curves were generated and placed in the following polynomials of the form:

$$A_{mN} = B_{m1} + B_{m2}m + B_{m3}m^2 + B_{m4}m^3$$

where

m = Altitude (Feet)

$$A_{m1} = 13.1 - 1.7 \times 10^{-4} m - 2.1 \times 10^{-7} m^2 + 3.7 \times 10^{-11} m^3$$

$$A_{m2} = 4.5 \times 10^{-2} - 7.9 \times 10^{-6} m + 3.8 \times 10^{-9} m^2 - 9.7 \times 10^{-13} m^3$$

$$A_{m3} = 1.3 \times 10^{-3} - 8.2 \times 10^{-7} m + 4.1 \times 10^{-10} m^2 - 8.5 \times 10^{-14} m^3$$

$$A_{m4} = 1.9 \times 10^{-5} + 1.4 \times 10^{-8} m - 9.5 \times 10^{-12} m^2 + 2.0 \times 10^{-15} m^3$$

4a.b. The enclosed computer program (following the Appendix) satisfies the requirements of steps 4.a and b, page 24. It coordinates all the input variables needed for computing take-off velocity and ground roll distance, and outputs those values within the accuracy required by Guideline 4 of page 13.

III. RESULTS

The results of this investigation were that:

1. A technique for reducing families of curves found in NATOPS manuals to simple equations that provide for proper interpolation was developed and tested.
2. A sample program for an entire performance example was prepared to illustrate the use of the polynomials in generating a solution to a typical performance problem.

The computational technique was utilized in providing coefficients for polynomials for all families of curves required to compute take-off roll and velocity for the A7E aircraft. A list of the program steps was included as an enclosure to this thesis. The curves of the charts for the ten input parameters were treated in a manner similar to the example of the previous section.

As can be seen from the equations of each section of the enclosed program the number of polynomial expressions required to describe a family of curves is not related to the number of curves within the family. Rather, it is a function of the degree of the curves within the family. If the degree of the curves were represented by the letter w , then the number of equations required (s) would be

$$s = w + 2$$

This fact caused significant reduction in the size, and an increase in the computational accuracy, of the final program. To illustrate an extreme example, the family of curves associated with computing the take-off distance wind correction will be referenced. It can be seen from this family (Located in Appendix A, page 11-38) that fifteen second degree curves were utilized to describe this correction. The total number of curves required to compute the correction using the method of this investigation was

$$s = 2 + 2 = 4 .$$

This included the three equations for computing the coefficients and one equation for coordinating the coefficients and computing the dependent variable from the output of the previous algorithm. It is worthwhile at this point to emphasize that these four equations were not only valid for the data that formed the given curves, but also for any intermediate values retaining the same accuracy. Alternate methods of using equations for all fifteen curves, plus a discrimination and interpolation routine, would produce less accurate results and require more computer space.

The sample program for take-off velocity and distance computation was implemented for demonstration purposes for the HP 9830. The program and computer combination met all

the requirements set forth in the guidelines with respect to ease of use, accuracy, speed, reduced memory required, and all around desirability. Informal tests with fleet aviators demonstrated that the program produced the same results as the charts but required less time by an order of magnitude, and little or no user effort. Implementation of the entire set of NATOPS curves on the HP 9830 desk computer would be unsuitable for aircraft use but could provide preflight and contingency planners with an invaluable tool for ground and shipboard use.

Concurrent investigations were performed in this area by Major J.D. Restivo, USMC, and Lt G.L. Koger, USN, at the Naval Postgraduate School. Major Restivo applied the technique of this thesis to the A6 aircraft NATOPS curves, while Lt Koger implemented the entire set of A7E curves in a "hand-held" calculator, namely, the Texas Instruments TI 59.

With the completion of this thesis, the feasibility of reducing the NATOPS performance data and curves has been demonstrated, and a procedure documented for the process. The responsibility for further investigation in this area has been assumed by Commander, Light Attack Wings, Pacific (COMLATWINGSPAC), Naval Air Station, Lemoore, California. To this end the following conclusions and recommendations are included as the final section.

IV. CONCLUSIONS AND RECOMMENDATIONS

It is concluded from this investigation that adaptation of the NATOPS performance data to digital computers for aircrew use was entirely feasible. Furthermore, a simple procedural method was found and demonstrated for reducing a large family of curves to a minimum number of polynomial expressions which could be coordinated in a program for precisely computing aircraft performance for any variation of the input parameters. Finally, it was shown that the computerized method of NATOPS presentation produced a quick and easy method for aircrews and planners to predict aircraft performance for missions and contingencies.

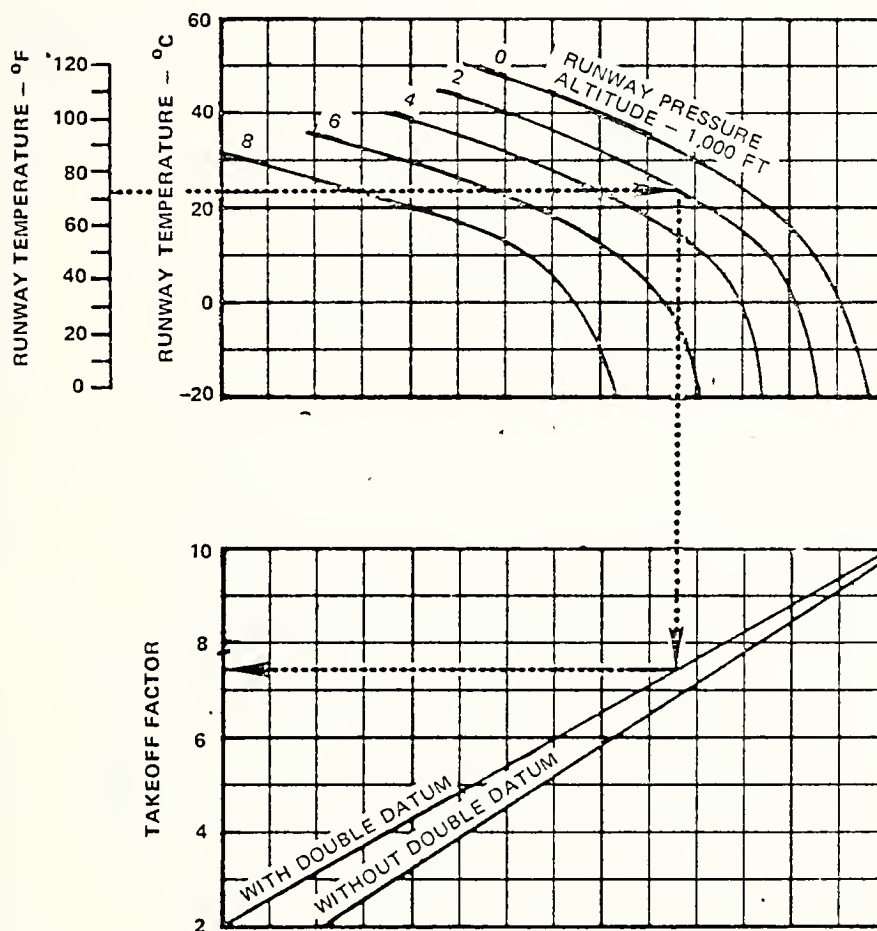
The following recommendations are made as a result of this study:

1. The activity which has been assigned the task of managing the research, development, and procurement for use by tactical aircraft crews should consider the procedures developed in this thesis study for achieving the end result.
2. Funds should be provided for a coordinated Navy-wide effort to ensure standardization of technique and hardware to reduce redundant efforts in this area of rapidly increasing interest.

TAKEOFF FACTOR (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL.



76F286-04-74

Figure 11-11

TAKEOFF GROUND ROLL DISTANCE (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

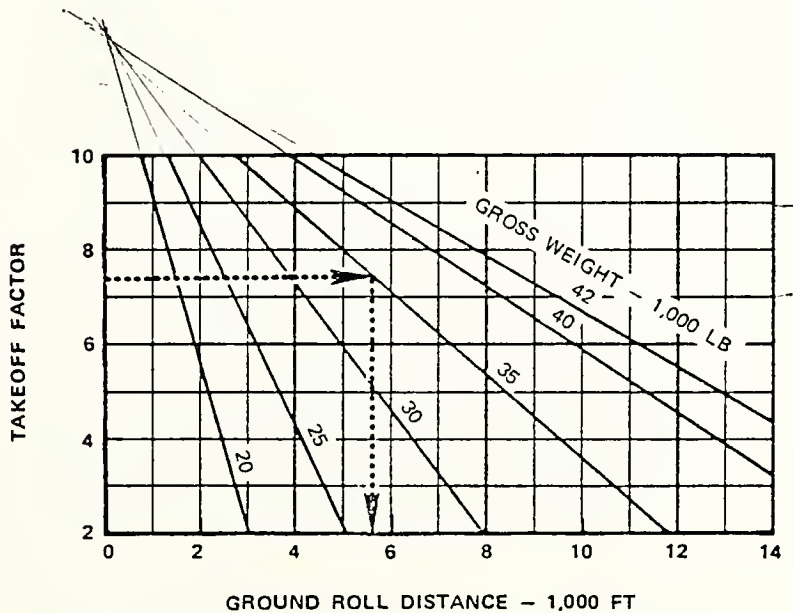
CONDITIONS:
LEVEL HARD SURFACE RUNWAY
MILITARY RATED THRUST
LANDING CONFIGURATION
ZERO HEADWIND
CG: 26% MAC
FULL FLAPS

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

NOTE

For minimum ground roll corresponding to minimum lift-off speed, subtract 500 feet.

For humidity effects on takeoff distance, ground roll distances should be increased 1% for each 10% increase in the relative humidity above 40%.



76E287(1)-04-74

Figure 11-12 (Sheet 1)

TAKEOFF GROUND ROLL DISTANCE (A-7E)

ADJUSTED GROUND ROLL DISTANCE

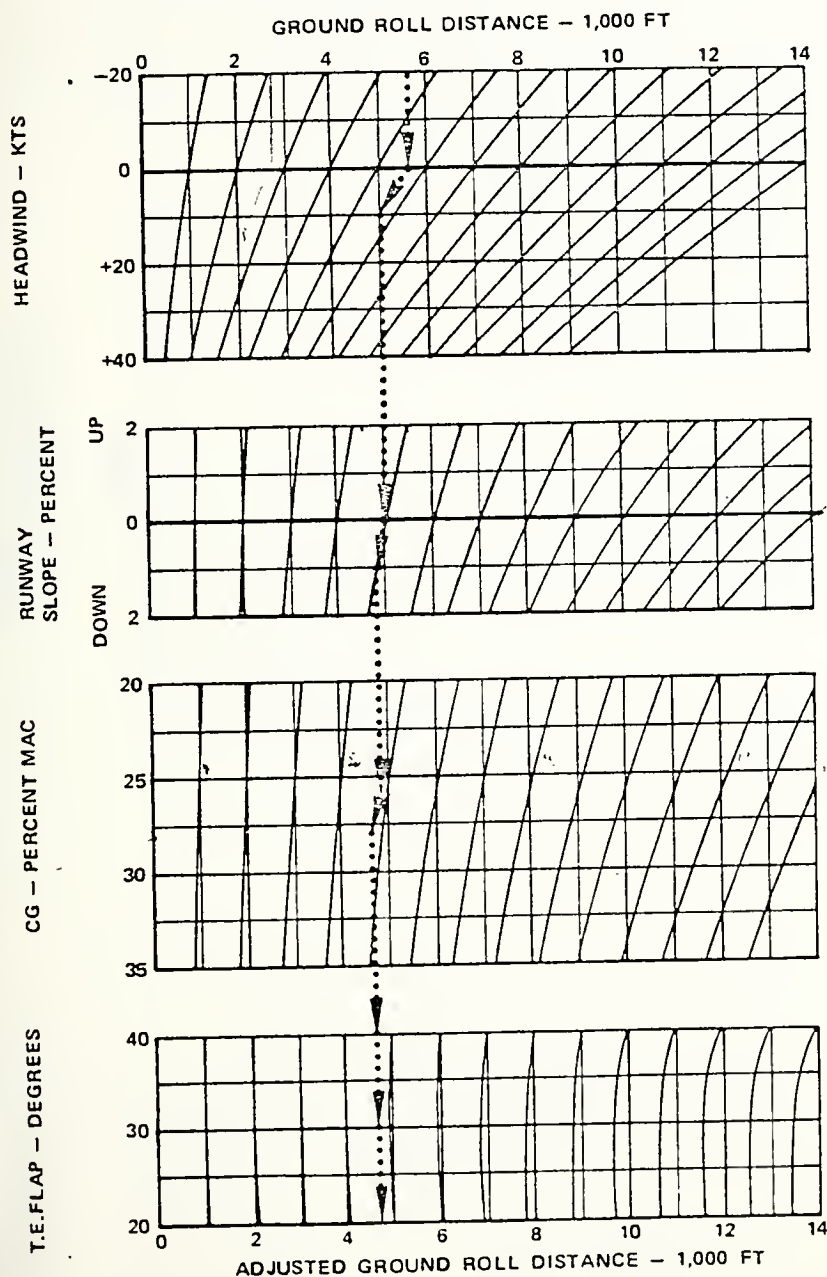
MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
HARD SURFACE RUNWAY
MILITARY RATED THRUST
LANDING CONFIGURATION
LEADING EDGE FLAPS DOWN

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

NOTES

For humidity effects on takeoff distance, ground roll distances should be increased 1% for each 10% increase in the relative humidity above 40%.



76E287(2)-01-72

Figure 11-12 (Sheet 2)

TAKEOFF SPEED (A-7E)

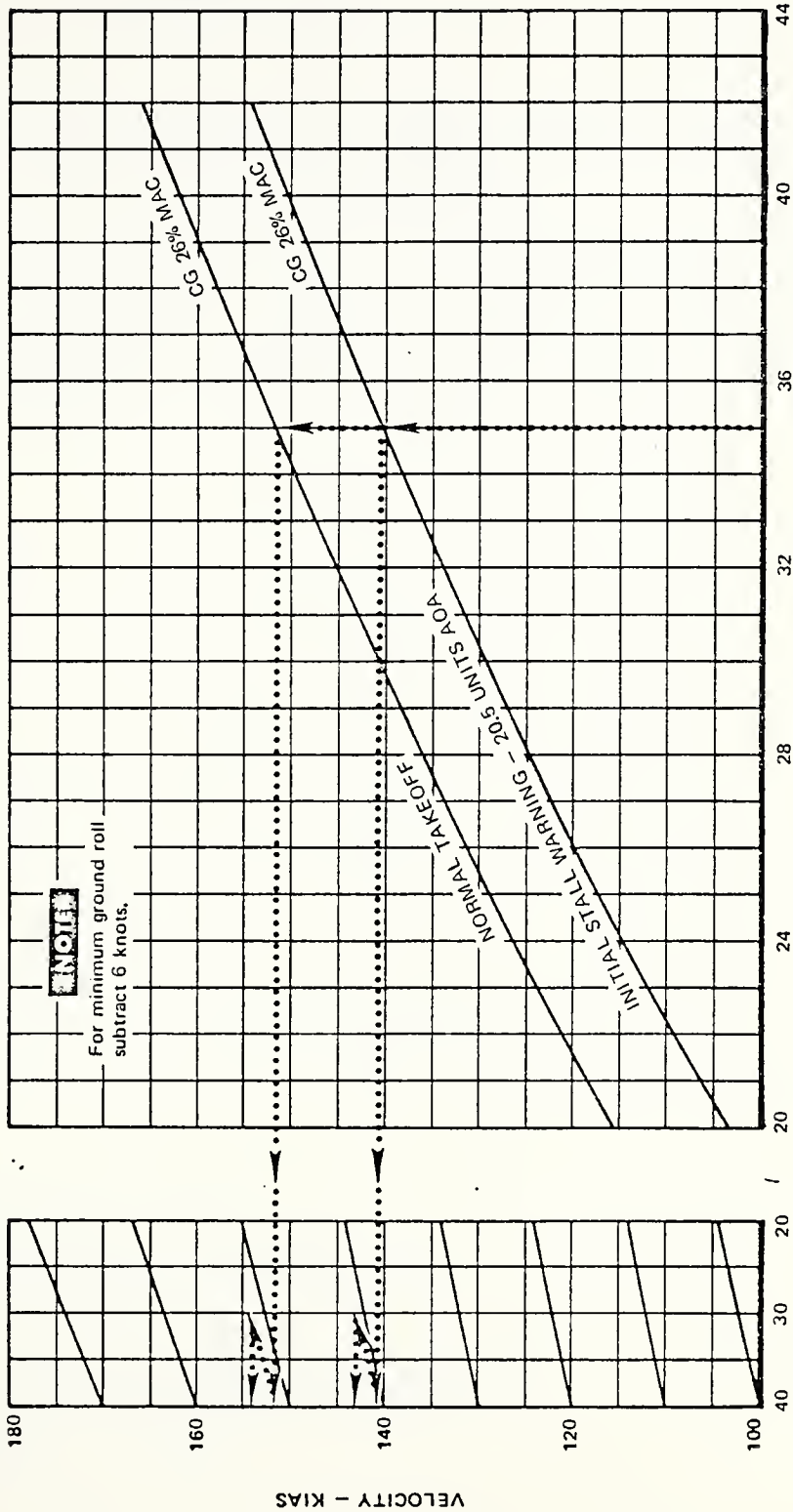
MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
MILITARY RATED THRUST
LANDING CONFIGURATION
LEADING EDGE FLAPS DOWN

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

NOTE

Data basis is 26% MAC. Increase speed 1/2 knot per 1% forward CG shift. Decrease speed 1/2 knot per 1% aft CG shift.



NOTE

For minimum ground roll subtract 6 knots.

T.E. FLAPS - DEGREES

GROSS WEIGHT - 1,000 LB

76E 254-02-72

Figure 11-13

APPENDIX B

A-7 NATOPS PROBLEM

An international incident has occurred which necessitates the rapid protection and extraction of U.S. military personnel within the strife stricken country.

You are the Commander of an A-7E squadron and have been given the task of planning and conducting the missions in support of the extraction of the U.S. personnel. Given the following information, determine the greatest distance from the target at which you could launch and return to the same take-off point.

1. Fuel Load - 14,000# (2,000# in each aero I D)
2. Ordnance Load
 - a. 1 AGM-45 (Skrike) on Sta #1 and Sta #8
 - b. 3 MK-20 (Rockeye) on Ter on Sta #2
 - c. 1 Aero I D (Full JP5) on Sta #3 and Sta #6
 - d. 1 AIM 9D (Sidewinder) on Sta #4 and Sta #5
 - e. 3 MK-83 (LDGP) on Ter on Sta #7
3. Basic Aircraft Weight - 21,000#
4. Area temperature at sea level - 30°C
5. Use 300# fuel for Start/Taxi/Catapult
6. Rendezvous at 10,000' and 25 NM - use 800# fuel during rendezvous
7. Descend from cruise altitude to target
 - a. Descend to 12,000'
 - b. Use 2,700#/Hr fuel flow
 - c. Maintain 370 Kts ground speed
 - d. Begin descent at 40 NM
8. Enroute winds are forecast
 - a. To the target - 40 Kts headwind
 - b. Return to ship - 70 Kts tailwind
 - c. Descents - no wind

9. Use 2,000# fuel in target area
10. Expend the following ordnance
 - a. 2 AGM-45
 - b. 3 MK-20
 - c. 3 MK-83
 - d. Retain all other racks, ordnance, tanks
11. Climb to cruise altitude for return will be from sea level.
12. Plan for Charlie on arrival with 1,000# internal fuel on the ball.

The following charts and tables have been taken from the NATOPS for your use.

APPENDIX C

Least Squares Fit Approximation

References 1 and 2 describe the Least Squares Fit Approximation in detail. In general the problem is to represent a set of "n" data points in two dimensional space

$$X_i, Y_i \quad i = 1 \text{ to } n$$

by a polynomial expression of a curve whose degree is less than "n". Two classes of problems exist:

1. Linearly independent - Those in which the degree (d) of the polynomial is one less than the number of data points

$$d = n - 1 \quad (1)$$

2. Linearly dependent - Those in which the degree (d) is less than n-1

$$d < n - 1 \quad (2)$$

As an example, a set of four (4) data points randomly spaced was chosen. If a third degree polynomial of the form

$$Y = A + BX + CX^2 + DX^3 \quad (3)$$

were desired, and the data points X_i and Y_i were inserted ($i = 1$ to 4) into four such equations, an exact solution for the four unknown coefficients would exist. These four unknowns could be found from the four equations by numerous conventional techniques (Direct substitution, Cramer's rule, etc.). The polynomial expression generated would be termed a "col-location" polynomial because its plot would pass through all data points.

It is often advantageous to describe a set of data points by a curve that does not pass through each point. This type of polynomial would be termed a "regression" equation. For any set of data points an infinite number of regression expressions exist for any specified degree (except the linearly independent case) and the object of the Least Squares Method is to find the polynomial coefficients of the chosen degree that best describe the data points. In the previous example of four data points, assume that, instead of the third degree form chosen, a second degree equation were selected of the form

$$Y = A + BX + CX^2 \quad (4)$$

With four data points, the polynomial is overspecified and thus linearly dependent. For this case an infinite number

of solutions exist for the coefficients a, b and c. If an error term (δ) were defined for any given X,Y pair as

$$\delta_1 = |Y_1 - A + BX_1 + CX_1^2| \quad (5)$$

a total squared error term (E) could then be defined by squaring and summing the terms attained:

$$E = \sum_{i=1}^N \delta_1^2 \quad (6)$$

If E were then minimized for any given degree chosen, the best Least Squares Fit would have been achieved.

If the values for δ from equation 5 were inserted in equation 6 and the partial derivative of E were taken with respect to the coefficient A an equation would be generated that when set equal to zero (0) would define a minimum value of E for a given value of A. If the same operation were performed with respect to the coefficients B and C then three equations would be generated with three unknowns (A, B, and C). The solution of these simultaneous equations would produce the coefficients A, B, and C, that would minimize the value of E and hence would produce a Least Squares Fit approximation to a set of linearly dependent equations.

A numerical procedure has been developed to accomplish this task. An example of this procedure has been included in the following paragraphs [Ref. 1 and 2].

Least Squares Fit Method Example

Given the following set of data:

X	0	1	2	4	7
f(X) = Y	0	1	3	12	20

fit a curve of the form

$$f(X) = Y = A + BX + CX^2$$

Step 1: Substitute all pairs of data into the form equation yielding the fact that the coefficients (A, B, & C) must satisfy all the following:

$$\begin{aligned}0 &= A + B(0) + C(0)^2 \\1 &= A + B(1) + C(1)^2 \\3 &= A + B(2) + C(2)^2 \\12 &= A + B(4) + C(4)^2 \\20 &= A + B(7) + C(7)^2\end{aligned}$$

Now multiply each expression by its coefficient of A in that expression and add all equations yielding

$$36 = 5A + 14B + 70C$$

Now multiply each expression by its coefficient of B in that expression and add all the expressions yielding

$$\begin{array}{rclcl}
0 & = & 0(A) & + & 0(B) & + & 0(C) \\
1 & = & A & + & 1B & + & 1C \\
6 & = & 2A & + & 4(B) & + & 8(C) \\
48 & = & 4A & + & 16(B) & + & 64(C) \\
140 & = & 7A & + & 44(B) & + & 343(C) \\
\hline
195 & = & 14A & + & 70(B) & + & 416(C)
\end{array}$$

Now multiply each expression by its coefficient of C in that expression and add all the expressions yielding

$$\begin{array}{rclcl}
0 & = & 0(A) & + & 0(B) & + & 0(C) \\
1 & = & 1(A) & + & 1(B) & + & 1(C) \\
12 & = & 4(A) & + & 8(B) & + & 16(C) \\
192 & = & 16(A) & + & 64(B) & + & 256(C) \\
980 & = & 49(A) & + & 343(B) & + & 2401(C) \\
\hline
1185 & = & 70A & + & 416B & + & 2674C
\end{array}$$

Now solve the following three previously generated equations for the coefficients A, B, & C yielding

$$\begin{array}{rclcl}
36 & = & 5A & + & 14B & + & 70C \\
195 & = & 14A & + & 70B & + & 416C \\
1185 & = & 70A & + & 416B & + & 2674C
\end{array}$$

$$A = -.99, \quad B = 2.6, \quad C = .065$$

and

$$Y = -.99 + 2.6X + .065X^2$$

The following chart and plot depict the original data and the data obtained from the equation for the fitted curve:

Original		Fitted Curve Polynomial
X	Y	Y
0	0	-.98
1	1	1.67
2	3	4.48
4	12	10.46
7	20	20.41

Q.E.D.

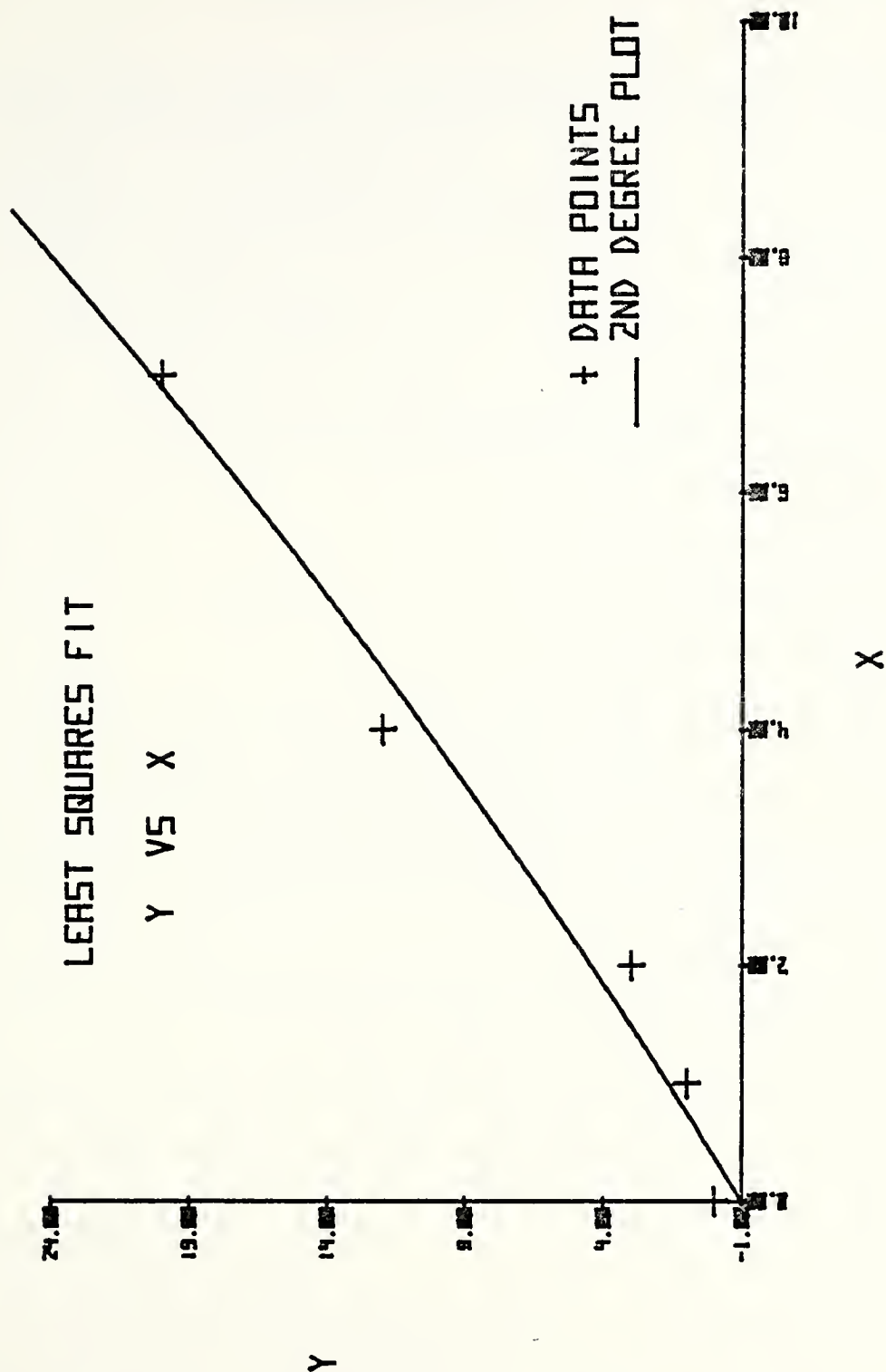


Figure XI Least Squares Fit Example

APPENDIX D

COMPUTER PROGRAM

```

1 PRINT " THIS PROGRAM COMPUTES A7E TAKE OFF ROLL AND VELOCITY. YOU WILL FILED"
2 PRINT "THE FOLLOWING INPUTS FOR THE COMPUTATION:"
3 PRINT
4 PRINT "1) RUNWAY PRESSURE ALTITUDE"
5 PRINT "2) RUNWAY TEMP IN DEG F"
6 PRINT "3) GROSS WT AND DOUBLE DATUM ON OR OFF"
7 PRINT "4) RELATIVE HUMIDITY"
8 PRINT "5) RUNWAY HEADING"
9 PRINT "6) WIND DIRECTION IN DEG MAG"
10 PRINT "7) WIND VELOCITY IN KTS"
11 PRINT "8) RUNWAY SLOPE IN %"
12 PRINT "9) A/C CG IN % MAC"
13 PRINT "10)T.E. FLAPS SETTING IN DEG"
14 PRINT
15 PRINT "IF YOU HAVE ALL THESE,PROCEED. WHEN COMPLETE CHECK YOUR ANSWER"
16 PRINT "AGAINST A7E NATOPS."
17 PRINT
18 DISP "PRESS ALT=";
19 INPUT A
20 IF A>8000 THEN 37
21 IF A<0 THEN 37
22 DISP "RUNWAY TEMP = ? DEG F";
23 INPUT B9
24 B=(B9-32)*5/9
25 IF B9>120 THEN 42
26 IF B9<0 THEN 42
27 B4=13.0863095227-0.0001711309*A-2.065456E-07*A+2+3.68613616E-11*A+3
28 B6=B4-2.4155714E-15*A+4
29 B5=-0.045634924-7.893101263E-06*A+3.75451107E-09*A+2
30 B1=B5-9.7087859E-13*A+3+6.9969745E-17*A+4
31 B6=-0.001316363990-8.25533140E-07*A+4.0739193788E-10*A+2
32 B2=B6-8.548790773E-14*A+3+5.4963933E-18*A+4
33 B7=-1.9097E-05+1.06707502395E-00*A-9.46943763E-12*A+2+2.043375E-15*A+3
34 B3=B7-1.46171876261E-19*A+4
35 C=B0+B1*B+B2*B+2*B3*B+3
36 GOTO 47
37 PRINT
38 PRINT "RUNWAY ALT MUST BE BTWN 0 AND 8000 FT, TRY AGAIN"
39 PRINT
40 PRINT "-----"
41 GOTO 18
42 PRINT
43 PRINT "TEMP MUST BE BTWN 0 AND 120 DEG F, TRY AGAIN"
44 PRINT
45 PRINT "-----"
46 GOTO 22
47 PRINT
48 PRINT "RUNWAY PRESS ALT =",A,"FT"
49 PRINT
50 PRINT "RUNWAY TEMP =",B9,"DEG F"
51 PRINT
52 PRINT "-----"
53 DISP "IF DD ON ENTER 1. IF NOT ENTER 0";
54 INPUT D
55 IF D=1 THEN 60
56 IF D=0 THEN 64

```


"PLEASE ENTER 1 OR 0, TRY AGAIN"

53
9700484+0.56590325*C
"DOUBLE DATUM ON"

65
4177767+0.65875515*C

"-----"
"GROSS WT=";

G
42000 THEN 81
20000 THEN 81
8896E+05+8.4974E+01*G-5.7856E-03*G+2+1.9373E-07*G+3-3.1744E-12*G+4
12.0446E-17*G+5
6621E+04-1.0146E+01*G+6.8807E-04*G+2-2.292E-08*G+3+3.7387E-13*G+4
-2.3964E-18*G+5
G1+E

"GROSS WT =",G,"LBS"

"-----"
6
"GROSS WT MUST BE BTWN 42000 AND 20000,TRY AGAIN"

"-----"
7
REL HUMIDITY = %;

I
THEN 99
00 THEN 99

0 THEN 93
0)/1000
H

"REL HUMIDITY =",I,"%"

"-----"
04
"REL HUMIDITY MUST BE BTWN 0 AND 100, TRY AGAIN"

"-----"
06
"ENTER RUNWAY HEADING";

Z
000 THEN 135
0 THEN 135
"ENTER WIND DIRECTION IN DEG MAG";

Y
000 THEN 135
0 THEN 135
"ENTER WIND VELOCITY";

X
Y-2)


```

115 L=X/COS(2*PI*M/360)
116 IF L>40 THEN 130
117 IF L<-20 THEN 130
118 IF L=0 THEN 124
119 L0=C.7124E+01+8.9509E-01*K+2.3306E-05*K+2-1.6254E-09*K+3.3738E-14*K+4
120 L1=-9.0995-1.0856E-03*K+2.1754E-07*K+2-2.5327E-11*K+3+1.197E-15*K+4
121 L2=1.4782E-01-2.1666E-06*K+3.4274E-09*K+2-2.7817E-13*K+3+9.3077E-10*K+4
122 M=L0+L1*L+L2*L+2
123 GOTO 125
124 M=K
125 PRINT
126 PRINT "HEADWIND =",L,"KTS"
127 PRINT
128 PRINT "-----"
129 GOTO 140
130 PRINT
131 PRINT "HEADWIND MUST BE BTWN -20 AND +40 KTS, TRY AGAIN"
132 PRINT
133 PRINT "-----"
134 GOTO 108
135 PRINT
136 PRINT "MAG HEADINGS MUST BE BTWN 0 AND 360, TRY AGAIN"
137 PRINT
138 PRINT "-----"
139 GOTO 104
140 DISP "R/W SLOPE = (+ FOR UP,-FOR DN)";
141 INPUT M
142 IF M>2 THEN 153
143 IF M<-2 THEN 153
144 Q0=4.5704E+01+9.3429E-01*M+2.2265E-05*M+2-2.338E-09*M+3+7.941E-14*M+4
145 Q1=7.9472+1.4914E-02*M+9.0708E-06*M+2-7.1235E-10*M+3+3.0684E-14*M+4
146 Q2=5.3616-8.5136E-03*M+3.5914E-06*M+2-4.5932E-10*M+3+1.9889E-14*M+4
147 Q=Q0+Q1*M+Q2*M+2
148 PRINT
149 PRINT "RUNWAY SLOPE =",M,"% "
150 PRINT
151 PRINT "-----"
152 GOTO 158
153 PRINT
154 PRINT "R/W SLOPE MUST BE BTWN -2 AND 2, TRY AGAIN"
155 PRINT
156 PRINT "-----"
157 GOTO 140
158 DISP "ENTER A/C CG(20 TO 35 %MAC)";
159 INPUT P
160 IF P>35 THEN 171
161 IF P<20 THEN 171
162 Q0=2.6042E+03-2.1694*0+1.0915E-03*0+2-1.1119E-07*0+3+3.662E-12*0+4
163 Q1=-1.7573E+02+2.2601E-01*0-7.5225E-05*0+2+7.7018E-09*0+3-2.5437E-13*0+4
164 Q2=2.8549-4.0102E-03*0+1.2832E-06*0+2-1.3234E-10*0+3+4.3908E-15*0+4
165 Q=Q0+Q1*P+Q2*P+2
166 PRINT
167 PRINT "CG =",P,"%MAC"
168 PRINT
169 PRINT "-----"
170 GOTO 176
171 PRINT
172 PRINT "CG MUST FALL BTWN 20 AND 35%MAC, TRY AGAIN"
173 PRINT
174 PRINT "-----"
175 GOTO 158

```



```

176 DISP "ENTER TE FLAP SETTING(20 TO 40)";
177 INPUT R
178 IF R>40 THEN 201
179 IF R<20 THEN 201
180 S0=-4.0079E+02+1.5801*Q-2.0254E-04*Q+2+2.4111E-08*Q+3-8.6737E-13*Q+4
181 S1=1.6196E+01-2.4333E-02*Q+9.3484E-06*Q+2-1.2594E-09*Q+3+4.7522E-14*Q+4
182 S2=-1.4758E-01+2.359E-04*Q-1.037E-07*Q+2+1.6016E-11*Q+3-6.3195E-16*Q+4
183 S=S0+S1*R+S2*R+2
184 T1=(INT(S/100))*100
185 T2=S-T1
186 IF T2>0 THEN 189
187 T=S
188 GOTO 190
189 T=((T1/100)+1)*100
190 PRINT
191 PRINT "TE FLAP SETTING =",R,"DEG"
192 PRINT
193 PRINT "-----"
194 PRINT "-----"
195 PRINT
196 PRINT "ADJUSTED GROUND ROLL =",T,"FT(ROUNDED UP TO NEAREST 100 FT)"
197 PRINT
198 PRINT "-----"
199 PRINT "-----"
200 GOTO 206
201 PRINT
202 PRINT "TE FLAP SETTING MUST BE BTWN 20 AND 40 DEG, TRY AGAIN"
203 PRINT
204 PRINT "-----"
205 GOTO 176
206 U1=5.4023E+01+3.4787E-03*G-1.9475E-08*G+2
207 U=U1+(26-P)/2
208 V0=-1.9171E+03+6.1604E+01*U-7.0348E-01*U+2+3.5661E-03*U+3-6.6578E-06*U+4
209 V1=7.6824E+01-2.4517*U+2.8779E-02*U+2-1.4753E-04*U+3+2.7872E-07*U+4
210 V2=-7.2239E-01+2.3415E-02*U-2.798E-04*U+2+1.4596E-06*U+3-2.807E-09*U+4
211 V3=V0+V1*R+V2*R+2
212 V4=INT(V3)
213 IF V3-V4=0 THEN 216
214 V=V4+1
215 GOTO 217
216 V=V3
217 PRINT
218 PRINT "TAKEOFF VELOCITY =",V,"KIAS (ROUNDED UP TO THE NEAREST 1 KT)"
219 PRINT
220 PRINT "-----"
221 GOTO 18
222 END

```


LIST OF REFERENCES

1. Gerald, C.F., Applied Numerical Analysis, p. 284-290, Addison-Wesley, 1973.
2. Wylie, C.R., Advanced Engineering Mathematics, 4th ed., p. 153-170, McGraw-Hill, 1975.
3. Toumela, C.H., Captain, USN(RET). Interview conducted at The Naval Postgraduate School, August 6, 1977.
4. Winters, K.A., Lieutenant, USN. Interview conducted at the Naval Postgraduate School, September 30, 1977.
5. A7E Naval Air Training Operational Procedures Standardization Manual, NAVAIR 01-45AEE -1, 15 March, 1975.
6. Hewlett-Packard 9830A Calculator Instruction Manual, Hewlett-Packard, 1972.

INITIAL DISTRIBUTION LIST

	No. Copies
1. Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2. Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3. Department Chairman, Code 67 Department of Aeronautics Naval Postgraduate School Monterey, California 93940	1
4. Professor L.V. Schmidt, Code 30 Department of Aeronautics Naval Postgraduate School Monterey, California 93940	5
5. LCDR W.M. Siegel 578 Tamarack Ln Lemoore, California 93245	4
6. Systems Exploration Inc. 419 Webster St. Monterey, Ca. 93940	1

Thesis 177106
S4934 Siegel
c.1 Computerization of
tactical aircraft

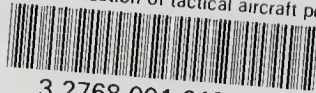
Thesis 177106
S4934 Siegel
c.1 Computerization of
tactical aircraft
performance data for
fleet application.

1 DEC 78	S12128
17 APR 79	25876
9 MAY 80	27023
3 NOV 80	26018
21 AUG 83	28593
DEC 2 85	30220

Thesis 177106
S4934 Siegel
c.1 Computerization of
tactical aircraft
performance data for
fleet application.

thesS4934

Computerization of tactical aircraft per



3 2768 001 91391 6

DUDLEY KNOX LIBRARY